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Development of asphalt pavement temperature model for tropical climate conditions in West Bali region

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Abstract

The temperature within the asphalt pavement layers varies due to the influence of environmental factors including air temperature, humidity, solar radiation, wind speed, and the reflectance of pavement surface. The temperature distribution on the cross section of asphalt pavement layer is considerably important in connection with the strength characteristics of various asphalt pavement designs. This study develops model of asphalt pavement temperature for tropical climate conditions in Indonesia which has a specific climate characteristics. Indonesia is located on a narrow range of latitudes (6° North - 11° South) and is crossed by the equator. Indonesia has a tropical climate and experiences lots of sunlight, rainfalls and high humidity throughout the year. The national road of Denpasar - Gilimanuk (Km 102) segment, Negara regency in the western of Bali is selected as a case study area. Thermocouples sensors equipped with data loggers were installed in various depths. Based on the SAGA Technology program, the temperatures were recorded every 30 minutes. About 336 observational data were recorded which include hourly variations of temperature and humidity as well as pavement temperature in various depth. It was found that there was a strong positive linear correlation ($r > 0.8$) between the air temperature and the temperature of the asphalt pavement. On the other hand, a strong negative linear correlation ($r > -0.8$) between the humidity and temperature of the pavement was found. Linear regression models were developed to predict the temperature of the asphalt pavement by using temperature and humidity as independent variables. The results indicated that the model has a good estimation accuracy.

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1. Introduction

Asphalt pavement is an open construction, so that the environmental factors affect the performance and its service life. Several environmental factors that affect the temperature are the temperature and humidity, solar radiation, wind speed, and the reflectance of the surface of the pavement. Temperature is one of the most important factors that significantly affect the mechanical properties of asphalt pavement [5]. Many researches mentioned that both air temperature and humidity are two of the most important environmental factors which significantly affect the mechanical of asphalt mixture properties, especially temperature of the asphalt pavement layers. Variations of air temperature and humidity directly affect the temperature of the asphalt pavement layer and the temperature distribution in the cross section of the asphalt pavement layer. This factor is important in determining the performance grade of asphalt and differences in the capacity of its structure. In the last decade, many studies have been conducted in several countries with different climates, such as in the United States [1, 8], Oman [3], Saudi Arabia [10], Spain [11], Iran [9], China [4], Portugal [6], Lithuania [9], and Serbia [5]. In some of those studies, the models were developed by considering the same parameters. The models were developed in the astronomical dominant subtropical climate with four seasons (spring, summer, autumn and winter). However, the models need to be adjusted if applied in other locations, especially in Indonesia, which has a specific climate characteristics. Indonesia is located in the region of small-latitude regions (6° North - 11° South) which is crossed by the equator. With this physical condition, Indonesian tropical climate is characterized by hot weather or receive relatively longer sunshine throughout the year. On the other hand, the Indonesian territory traversed by two movements of the monsoon (monsoon west and east monsoon) which causes parts of Indonesia experienced two seasons: the rainy season in the period from October to March and the dry season in the period from April to September, and about 70% Indonesian territory is water, so that Indonesia has a sea climate with features such as the air often cloudy, wet (high humidity) and have a high rainfall. Therefore, it is required to develop model of asphalt pavement temperature profile by taking the area of Bali as a case study area for this typical climate. This research was conducted on a national road Denpasar - Gilimanuk (Km 102) segment, Negara regency in the western of Bali island, Indonesia.

Nomenclature

| | | | |
|---------|------------------------------|-------|--|
| T.Air | Air temperature | T.00 | Surface asphalt pavement temperature, at 00 mm depth |
| r | Correlation | T.20 | Asphalt pavement temperature at 20 mm depth |
| R2 | Coefficient of determination | T.70 | Asphalt pavement temperature at 70 mm depth |
| F | Statistics F | t | Statistics t |
| VIF | Variance Inflation factor | AC-WC | Asphalt concrete wearing course |
| SSE | Standard error of estimate | AC-BC | Asphalt concrete binder course |
| Z-score | Standardized score | | |

2. Field data collection

An observation station was placed on the national road of Denpasar – Gilimanuk (Km 102) segment, which is located in Negara regency in the western of the Bali island, Indonesia as shown in Fig. 1.(a) in order to monitor and record the fluctuations of the air temperature, humidity and temperature at various depths of the pavement layer. To minimize the influence of other climatic factors on pavement humidity, measurements were conducted during the sunny weather in the dry season. Fig. 1. (b) shows position of the sensors for measuring asphalt pavement temperature, and Fig. 1. (c) shows position of the sensors to measure air temperature and humidity. A measurement sensor was connected to the signal processor using a microcontroller of ATMEGA8 as shown in Fig. 2.(a). This was used to be the signal processing and data communications controller between sensors. In a serial data format, an interface connected the microcontroller with a computer to display (Fig. 2.(b)) and record the measured data through a customized application program developed by SAGA Technology as shown in Fig. 2. (c).

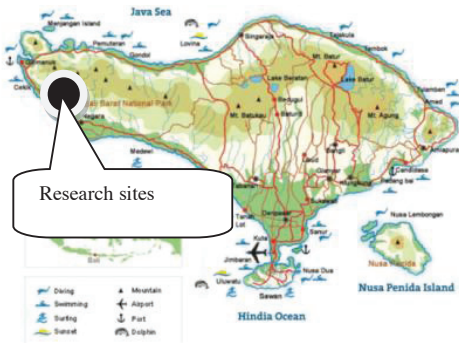


Fig. 1. (a) Research location, in the western of Bali island Indonesia;

(b) sensors position for measuring pavement temperature;

(c) sensor position for measuring humidity



Fig. 2. (a) Microcontroller ATMEGA8

(b) data display

(c) data recorder

3. Characteristics of air temperature, humidity and asphalt pavement temperature

Observations and measurements were made every day for the total of ten days in the month of August 2014 and the temperature was recorded every 30 minutes. Data were collected over a period of ten days during the dry season and sunny weather (from 20 August to 30 August 2014), which include air temperature, humidity and asphalt pavement temperature in various depths. Asphalt pavement temperature measurements were carried out on the overlay layer (on the surface of the asphalt pavement (00 mm)), in 20 mm depth, which was in the middle of a thick layer of the surface (AC-WC) and in 70 mm depth, which was in the middle layer (AC-BC). Local air temperature was also measured at the height of approximately 1.5 meters above the surface of the asphalt pavement. The hourly variations patterns of temperature and humidity, the asphalt pavement temperature on the surface pavement, at 20 mm and 70 mm depths are shown in Fig. 3(a, b, c,d) and Fig. 4(a) where as the comparison of the average value is given in Fig. 4(b).

The pattern of variation of asphalt pavement temperature on all relatively the same depth follows the pattern of variations air temperature but opposite to the pattern of humidity. A process of increasing and decreasing the temperature within the same relative time scale occurred. Along with the increase in the air temperature and on the other hand there is a decrease in air humidity, there will be an increase in the temperature of the asphalt pavement at all depths and sharp increase in the period 10:00 to 14:30. Recorded maximum values during the observation process in T.Air = 31.85 °C (12:30); RH = 89.93% (22:30); T.00 = 57.31 °C (13:00); T.20 = 51.75 °C (14:00) and T.70 = 48.44 °C (14:30). The time difference of the occurrence maximum temperature value on the underneath pavement was a result of the process of heat conduction. For minimum values, at T.Air = 22.35 °C (6:00); RH = 53.97% (12:30); T.00 = 23.44 °C (6:30); T.20 = 24.6 °C (06:30) and T.70 = 26.06 °C (07:00). It can be seen that the asphalt pavement temperature has a higher value than the air temperature. For the inter depth asphalt pavement temperature, the heating process T.00 has a higher value than the depths below. On the other hand, during the

cooling process T.00 experienced a faster decrease, resulting in a certain period of time T.20 or T.70 which has a higher value. Details of heating and cooling processes can be seen also in comparison the average value T.Air; RH; T.00; T.20; T.70 in Fig. 4 (b).

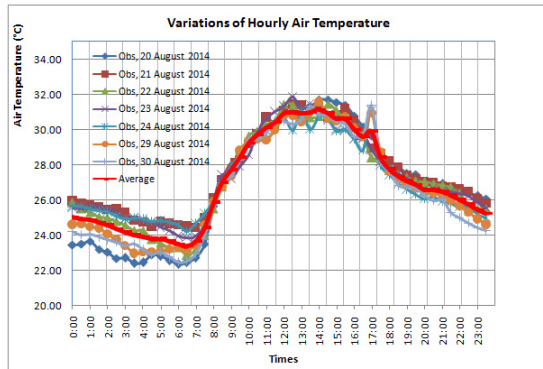
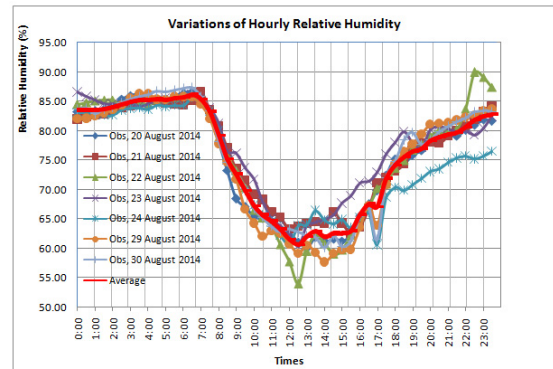
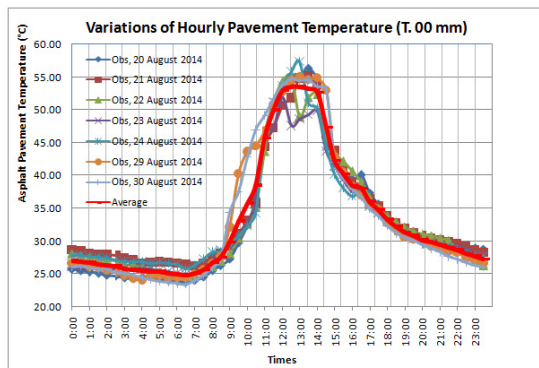


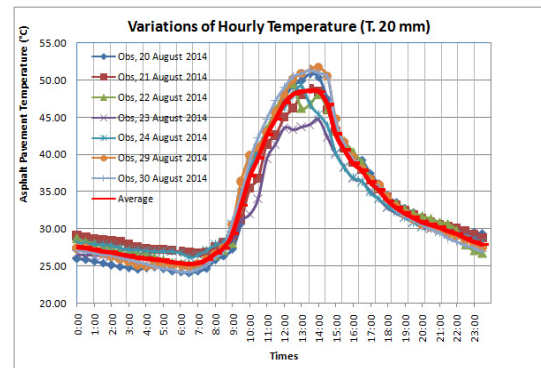
Fig. 3. (a) Variations of hourly air temperature;



(b) variations of hourly relative humidity;



(c) variations of hourly pavement temperature at 00 mm depth;



(d) variations of hourly pavement temperature at 20 mm depth

4. Summary of the descriptive statistic

Table 1 shows the summary of the descriptive statistics of all variables used in the regression models that include the mean, median, standard deviation, variance, skewness, kurtosis, minimum and maximum of the 336 total number of sample observations. It can be seen that the values of skewness indicates that the distribution of all variables are not perfectly normal. The data are skewed to the left or to the right, but the values are still within tolerable limits. Based on the results of the value conversion data for all variables into standardized score (Z-score), there are no extreme value of variable data which is differ much from other observations (outliers).

Correlation matrix between the variables used in the regression model can be shown in Table 2. The correlation between variables have a strong value that is above 0.8 and there is a positive correlation between variables T.Air and T.00; T.20; T.70. This indicates that the increasing value of T.Air will lead to the increase on the value of T.00, T.20 and T.70. On the other hand, there is a negative correlation between variables RH and T.00; T.20; T.70. For variable T.Air and RH, there is a very strong negative correlation ($r = -0.951$), this indicates that there will be a very large value changes if one value is changed.

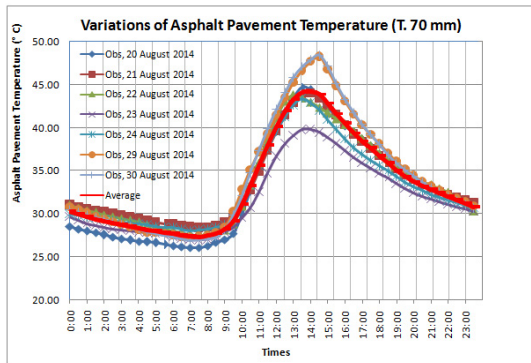
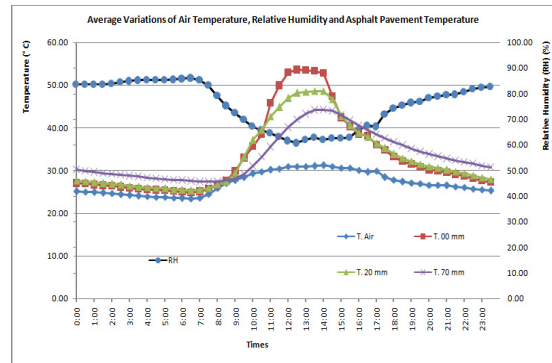


Fig. 4.(a) variations of hourly pavement temperature at 70 mm depth;



(b) hourly average variations of air temperature, humidity and asphalt pavement temperature

Table 1. Summary statistics

| | T. Air (°C) | RH (%) | T.00 (°C) | T.20 (°C) | T.70 (°C) |
|--------------------|-------------|---------|-----------|-----------|-----------|
| N Valid | 336 | 336 | 336 | 336 | 336 |
| Mean | 27.0272 | 75.6013 | 33.3447 | 33.0229 | 33.4304 |
| Median | 26.7050 | 78.0500 | 29.4050 | 30.0900 | 31.8100 |
| Standard deviation | 2.68516 | 9.09063 | 9.31731 | 7.74248 | 5.60483 |
| Variance | 7.210 | 82.640 | 86.812 | 59.946 | 31.414 |
| Skewness | .148 | -.427 | 1.145 | .908 | .771 |
| Kurtosis | -1.194 | -1.271 | .060 | -.418 | -.460 |
| Minimum | 22.35 | 53.97 | 23.44 | 24.06 | 26.06 |
| Maximum | 31.85 | 89.93 | 57.31 | 51.75 | 48.44 |

Table 2. Correlation matrix

| Variable | T.Air (°C) | RH (%) | T.00 (°C) | T.20 (°C) | T.70 (°C) |
|------------|------------|---------|-----------|-----------|-----------|
| T.Air (°C) | 1 | -.951** | .891** | .925** | .853** |
| RH (%) | -.951** | 1 | -.897** | -.928** | -.835 |
| T.00 (°C) | .891** | -.897** | 1 | .983** | .873** |
| T.20 (°C) | .925** | -.928** | .983** | 1 | .915** |
| T.70 (°C) | .853** | -.835** | .873** | .915** | 1 |

** Correlation is significant at the 0.01 level (2-tailed)

5. Development of asphalt pavement temperature models

Linear regression model was developed to describe the relationship between temperature and humidity with temperatures pavement at 00 mm depth (T.00), 20 mm depth (T.20) and 70 depth mm (T.70) as shown in Table 3. For T.00, models were built with two independent variables (T.Air, RH) which has a goodness of fit (Adjusted $R^2 = 0.818$) with SSE 3.97061°C and the value of the F and t statistic test, have the significance probability of 0.000. So it can be said that T.00 value can be explained by two variables accurately. However, collinearity was identified as there is a very strong correlation ($r = 0.951$) between independent variables. This can be seen from the collinearity statistics (tolerance $0.096 < 0.1$ or $VIF > 10$) and there autocorrelation between residual variables in the model. For T00, another alternative models developed by considering the independent variables of the air temperature or humidity.

There are several alternatives linear regression models were developed for T.20 as shown in Table 3. Model T.20

using three independent variables (T.Air, RH, T.00) gives goodness of fit (adjusted $R^2 = 0.979$) that means 97.9% T.20 can be explained by variations of variables T.Air, RH and T.00. This model also has the value of the F and t statistics test with significance probability of 0.000, which means the accuracy of the model can be described individually or simultaneously by these three variables. On the other hand, collinearity (tolerance $0.088 < 0.1$ or VIF $11.325 > 10$) is identified as there is a strong correlation ($r = 0.755$) among variables T.Air and RH and there is autocorrelation between residual variables in the model. Several alternative models were developed further by varying T.20 with two independent variables and one independent variable.

Table 3. Alternative models of asphalt pavement temperature

| Models | Adjusted R^2 | SSE | F | Tolerance | VIF |
|--|----------------|---------|----------|-----------|--------|
| $T.00 = 35.013 + 1.405T.Air - 0.524RH$ | .818 | 3.97061 | 755.822 | .096 | 10.416 |
| $T.00 = -50.240 + 3.093T.Air$ | .794 | 4.23156 | 1290.150 | | |
| $T.00 = 102.813 - 0.919RH$ | .803 | 4.13386 | 1367.842 | | |
| $T.20 = 8.963 + 0.425T.Air - 0.105RH + 0.616T.00$ | .979 | 1.13254 | 5108.246 | .088 | 11.325 |
| $T.20 = -6.898 + 0.687T.Air + 0.640T.00$ | .977 | 1.16456 | 7237.250 | .206 | 4.863 |
| $T.20 = 26.968 - 0.202RH + 0.640T.00$ | .977 | 1.18082 | 7034.759 | .196 | 5.095 |
| $T.20 = -39.058 + 2.667T.Air$ | .855 | 2.94770 | 1977.212 | | |
| $T.20 = 92.753 - 0.790RH$ | .860 | 2.89596 | 2060.524 | | |
| $T.70 = -1.694 + 0.816T.Air + 0.024RH + 0.337T.00$ | .788 | 2.58018 | 416.258 | .088 | 11.325 |
| $T.70 = 1.965 + 0.755T.Air + 0.331T.00$ | .789 | 2.57710 | 625.777 | .206 | 4.863 |
| $T.70 = 32.893 - 0.163RH + 0.384T.00$ | .775 | 2.65776 | 578.417 | .196 | 5.095 |
| $T.70 = -14.685 + 1.780T.Air$ | .727 | 2.93060 | 891.344 | | |
| $T.70 = 72.336 - 0.515RH$ | .696 | 3.09155 | 767.077 | | |

The development of T.70 was done by considering several variations of the independent variables. For T.70 with variations of two independent variables, the model gives the value of goodness of fit (adjusted $R^2 = 0.798$ and 0.775 , respectively), the value of the F statistic and t test with significance probability of 0.000 and there is no collinearity between independent variables. In both of these models, there is autocorrelation between residual variables, in connection with data retrieval methods are time series. Models that take into account the independent variable (T.Air or RH) were also developed for T.70 (see Table 3). The following model is proposed to predict the pavement temperature at each depth:

$$T.00 = 10.813 - 0.919RH \quad (1)$$

$$T.20 = -6.898 + 0.687T.Air + 0.640T.00 \quad (2)$$

$$T.70 = 1.965 + 0.755T.Air + 0.331T.00 \quad (3)$$

6. Conclusions

Climate is influenced by the latitude position. An observation station was placed on the national road of Denpasar-Gilimanuk (Km 102) segment, which is located in Negara regency in the western of the Bali island, Indonesia to monitor and record the fluctuations in the air temperature, humidity and temperature at various depths of the asphalt pavement layers. Asphalt pavement temperature profile has the same pattern as the air temperature profile but opposite to the pattern of humidity profiles. Due to the increased in air temperature, there was a sharp increase in the temperature of the asphalt pavement in the period 10:00 to 14:00. The minimum temperature of the asphalt pavement occurred in the period of 6:00 to 07:00 while the maximum temperature occurred in the period of 13:00 to 14:00.

Effect of the climatic environment (air temperature and humidity) at the asphalt pavement temperature is very strong ($r > 0.8$) and some alternative regression models were developed to predict the asphalt pavement temperature using air temperature or humidity as independent variables. Selected models are based on statistical tests such as

goodness of fit (adjusted R^2), the statistics F and t test, collinearity test which give a good results. For the residual models, several statistical test were conducted such as autocorrelation test, heteroscedasticity test, and normality test. In general, all of the models were found to have a good accuracy.

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